AFRL-HE-WP-TP-2005-0012

AIR FORCE RESEARCH LABORATORY

Assessment of an Optically Stimulated Infrared Emission From Image Intensifier Tube Photocathodes

Jesse Wales
Peter Marasco

Human Effectiveness Directorate
Warfighter Interface Division
Wright-Patterson AFB OH 45433-7022

October 2005

Final Report for the Period September 2003 to February 2005

Human Effectiveness Directorate
Warfighter Interface Division
Wright-Patterson AFB OH 45433

NOTICES

TECHNICAL REVIEW AND APPROVAL

AFRL-HE-WP-TP-2005-0012

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

//Signed//

MARIS M. VIKMANIS
Chief, Warfighter Interface Division
Air Force Research Laboratory

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. **PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**

1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE	3. DATES COVERED (From - To)
25-Oct-2005	Final Report	Sep 03 to Feb 05

4. TITLE AND SUBTITLE
Assessment of an Optically Stimulated Infrared Emission From Image Intensifier Tube Photocathodes

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Jesse G. Wales
Peter L. Marasco

5d. PROJECT NUMBER 7184

5e. TASK NUMBER 11

5f. WORK UNIT NUMBER 23

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) AND ADDRESS(ES)

8. PERFORMING ORGANIZATION REPORT NUMBER
AFRL-HE-WP-TP-2005-0012

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
*Air Force Materiel Command
Air Force Research Laboratory
Human Effectiveness Directorate
Warfighter Interface Division
Wright-Patterson AFB OH 45433-7022

10. SPONSOR/MONITOR'S ACRONYM(S)
AFRL/HECV

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
Clearance AFRL/WS-05-0313, 11 Feb 05

14. ABSTRACT Purpose
Anecdotal evidence suggested that bright, night-vision imaging system (NVIS) compatible, green cockpit displays could cause a veiling luminance in night-vision goggles (NVGs) and degrade visual performance. The mechanism suspected of causing this veiling luminance was an infrared emission from the image intensifier tube photocathode stimulated by visible, NVIS compatible light. This paper describes an effort to measure this stimulated infrared emission from three different image intensifier tubes. Measurements of the emission were analyzed with respect to tube age, the wavelength of incident illumination, and illumination angle of incidence. The emission was found during certain combinations of light wavelengths, angles, and intensities. However, results suggest that this phenomenon is not sufficiently strong to cause observable veiling luminance in NVGs.

15. SUBJECT TERMS
Night vision, goggles, NVG, photocathode, near infrared, NIR, emission, image intensifier tube

16. SECURITY CLASSIFICATION OF: Unclassified			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Jesse Wales, 1Lt, USAF
UNC	UNC	UNC	SAR	13	19b. TELEPHONE NUMBER (include area code) (937)255-8361

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. 239.18

THIS PAGE INTENTIONALLY LEFT BLANK

Assessment of an Optically Stimulated Infrared Emission from Image Intensifier Tube Photocathodes

Jesse G. Wales and Peter L. Marasco
Air Force Research Laboratory, Battlespace Visualization Branch, AFRL/HECV
2255 H Street, Wright-Patterson AFB, OH 45433-7022

ABSTRACT

Anecdotal evidence suggested that bright, night-vision imaging system (NVIS) compatible, green cockpit displays could cause a veiling luminance in night-vision goggles (NVGs) and degrade visual performance. The mechanism suspected of causing this veiling luminance was an infrared emission from the image intensifier tube photocathode stimulated by visible, NVIS compatible light. This paper describes an effort to measure this stimulated infrared emission from three different image intensifier tubes. Measurements of the emission were analyzed with respect to tube age, the wavelength of incident illumination, and illumination angle of incidence. The emission was found during certain combinations of light wavelengths, angles, and intensities. However, results suggest that this phenomenon is not sufficiently strong to cause observable veiling luminance in NVGs.

Keywords: Night vision, goggles, NVG, photocathode, near infrared, NIR, emission, image intensifier tube

1. INTRODUCTION

The phenomenon was first observed by the Navy. Naval aviators noted that under certain circumstances when wearing NVGs, their cockpits, known to be adequately NVIS compatible, seemed to cause visual performance losses due to NVIS compatible displays outside their field of view. The Navy's examination of the problem ended after it concluded that lens hoods, fitted to the NVG objective lenses, eliminated the visual performance losses. The source of the veiling glare was the subject of considerable speculation. Some in the NVG community suspected that the objective lens, or some part of it, such as a coating, was the heart of the phenomenon. Other NVG experts in the Air Force hypothesized that the image intensifier tube's (I^2T) photocathode was the problem. The idea was that the photocathode, comprised of Gallium Arsenide (GaAs), a known near infrared emitter, might be stimulated to emit infrared light by incident visible light. It was thought that when light of certain wavelengths and incident at certain angles struck the photocathode, it would cause an infrared emission. If this emission was large enough and at a wavelength the NVGs are sensitive to, it might explain the problem. The Air Force Research Laboratory, Battlespace Visualization Branch (AFRL/HECV) at Wright Patterson AFB conducted the study described in this paper to test this hypothesis.

Researchers desired to study the magnitude of the phenomenon with respect to a number variables: illumination intensity and wavelength, illumination angle, and measurement angle. Illumination intensity was studied to test the linearity of the emission's magnitude. Illumination wavelength was of particular interest. Since photon energy is directly related to photon frequency (and inversely proportional to wavelength), one would anticipate the phenomenon is wavelength dependent. Since the IR emission only seemed to be noticeable when the light source was outside the NVG field of view, angle of illumination (measurements made normal to the photocathode surface) was also seen as a potentially significant variable. Measurement angle (illumination normal to the photocathode surface) was also examined to test the Labertian nature of the emission. The spectral location of the phenomenon was not expected to change. The bandgap structure of GaAs suggested that the IR emission should occur at the same combination of wavelengths regardless of the magnitude or wavelength, photon energy) of the incident illumination[1].

2. EXPERIMENT

The focus of this effort was to measure the stimulated IR emission directly from the photocathode. The experiment was to illuminate the image intensifier tube's photocathode with narrow-band, short-wavelength light, stimulating the phenomenon, and then measure the spectral radiance of the photocathode. Measurements of photocathode spectral radiance would be made for a number of experimental configurations (physical setup) and illumination conditions. The measurements would be repeated for a particular measurement geometry and illumination with the image intensifier tube power on, to assess the impact of the electrical state of the tube on photocathode radiance.

To achieve the experimental goal, a highly sensitive light measurement system was required. Measurements of the both the incident light and the photocathode return were made using a high-sensitivity spectroradiometer capable of measuring the NVIS compatibility of sources. Using the spectroradiometer, the radiance of the photocathode face of an I^2T was measured in 1nm wavelength intervals from 380nm to 930nm for each of the experimental conditions. The measurement bandwidth of the radiometer was set to 8.57 nm.

To stimulate the IR emission, a high-intensity spectrally narrow, wavelength-selectable light source was required. The light source consisted of a 300W tungsten halogen lamp passed through a light diffuser and a monochromator. The wavelength of light was selected with the monochromator at a set bandwidth of 5nm. A pair of focusing lenses were used to improve overall light throughput. Figure 1, below, shows a simple block drawing of the equipment. Figure 2 shows two pictures of the experiment apparatus. Here, θ is the angle between the incident light and the measurement lens and d is the distance between the measurement lens and the photocathode face. The geometry of the apparatus was chosen such that the major reflections from the incident light off the photocathode face were minimized. At no time was the measurement lens in the direct line of the reflections.

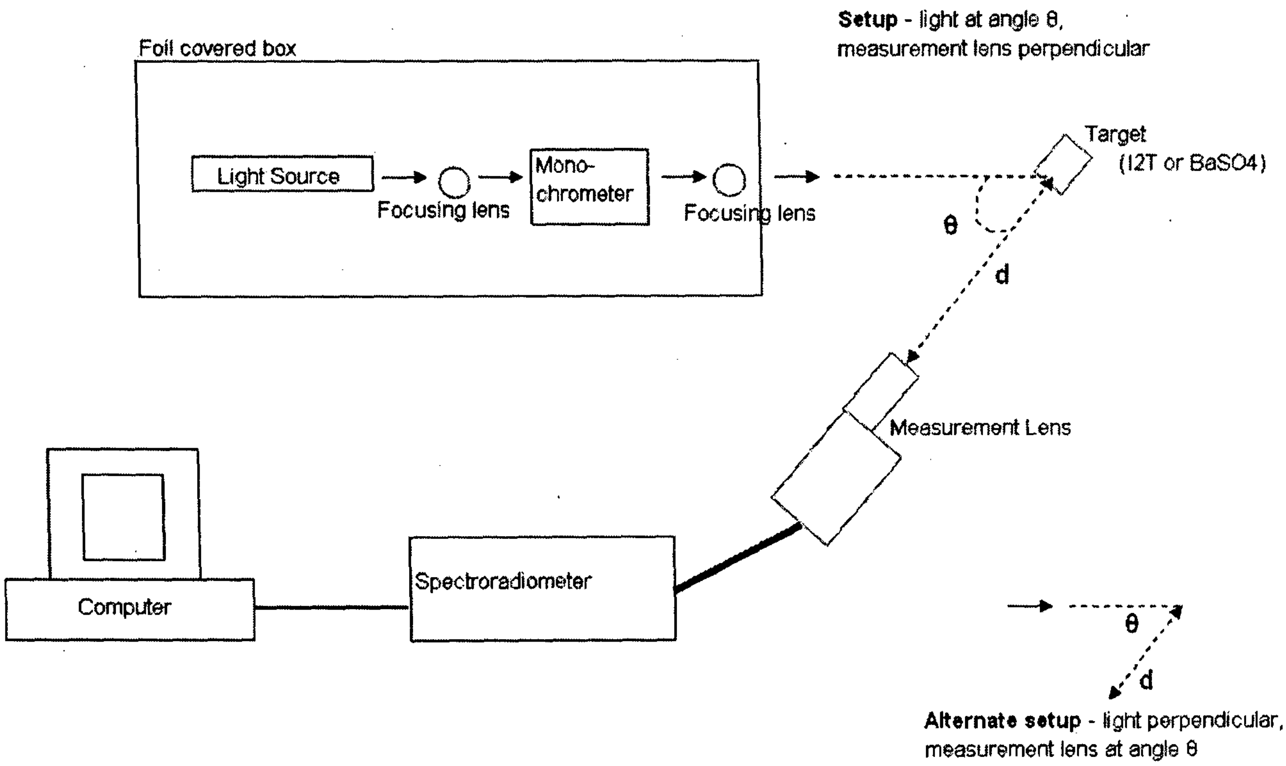

Figure 1. Drawing of experiment apparatus.

Figure 2. Two pictures of experiment apparatus. The slide projector powered the light source and the monochromator set the wavelength. The lenses focused the light onto the photocathode face of the image intensifier tube. Measurements were taken with the spectroradiometer and measuring lens.

A spectral scan of each photocathode's radiance was taken for several incident light conditions. The conditions were varying incident light wavelengths, light intensity, incident light angles (with measurement head perpendicular to I^2T) and measurement head angles (with incident light perpendicular to I^2T). Table 1, below, lists the variables used. The $BaSO_4$ reflectance standard was used to measure how much light was incident on the I^2T ($BaSO_4$ radiance). For each condition, the incident radiance was measured from the $BaSO_4$ as the target. The light wavelengths were selected to cover a broad range of visible light. The incident light angles are the angles that the light hit the photocathode. This range was selected to determine if the IR radiance was influenced more strongly by light incident at angles greater than those corresponding to the edge of the 40-degree field of view common in night vision devices (since the Navy's lens hood reduced the visual performance loss). The 'brighter light' refers to a set of measurements taken with the light diffuser removed from the front of the light source. This increased the amount of incident light, but also caused the light to be brighter in some spots on the photocathode face than others. In order to further examine the IR radiance, a set of measurements were also taken with the incident light perpendicular to the face of the photocathode and the measurement lens measuring the radiance emitted at different angles. Finally, one measurement was conducted with an I^2T powered on (the phosphor screen side of the I^2T was taped off so that the green phosphor light didn't influence the measurement of the photocathode face). This was done to determine if the powered microchannel plate contributed to the stimulated IR radiance.

Targets	**Incident Light Wavelengths**	**Incident light angles**	**Measurement head angles**
BaSO4 reflectance standard	450nm	15 degrees	10
I^2T 1	475nm	30 degrees	30
I^2T 2	500nm	45 degrees	
I^2T 3	525nm	60 degrees	**(incident light perp. to I^2T)**
I^2T 2 powered on	550nm	30 degrees with brighter light	
	575nm		
	600nm	**(measurement lens perpendicular to I^2T)**	
	625nm		
	650nm		
	675nm		
	700nm		

Table 1. Experiment variables.

Three image intensifier tubes were used, labeled I^2 tubes 1, 2, and 3. These three tubes were of varying age. Tube 1 was the oldest, assembled sometime in the mid 1980's. Tube 2 was the newest tube out of the three, assembled sometime in the mid 1990's. Unfortunately, more accurate data was not available on the age of the tubes used in this effort.

3. RESULTS

When visible light of certain wavelengths and intensities were incident on the photocathode end of an I^2 tube, a stimulated IR emission was detected. An obvious peak could be seen in the range of 800-900 nm. Figure 3 below is an illustration of this event. The dashed line is the incident light (measured from the $BaSO_4$ reflectance standard). The solid line is the light measured from the photocathode end of an I^2 tube. If the light measured from the bare image tube photocathode was strictly due to reflection, one would expect its magnitude to be less than the magnitude of the incident light, measured from the $BaSO_4$ target for all wavelengths. However, as seen in Figure 3, the return from the photocathode is greater than the illumination for wavelengths longer than 800nm, indicating the presence of a stimulated IR emission.

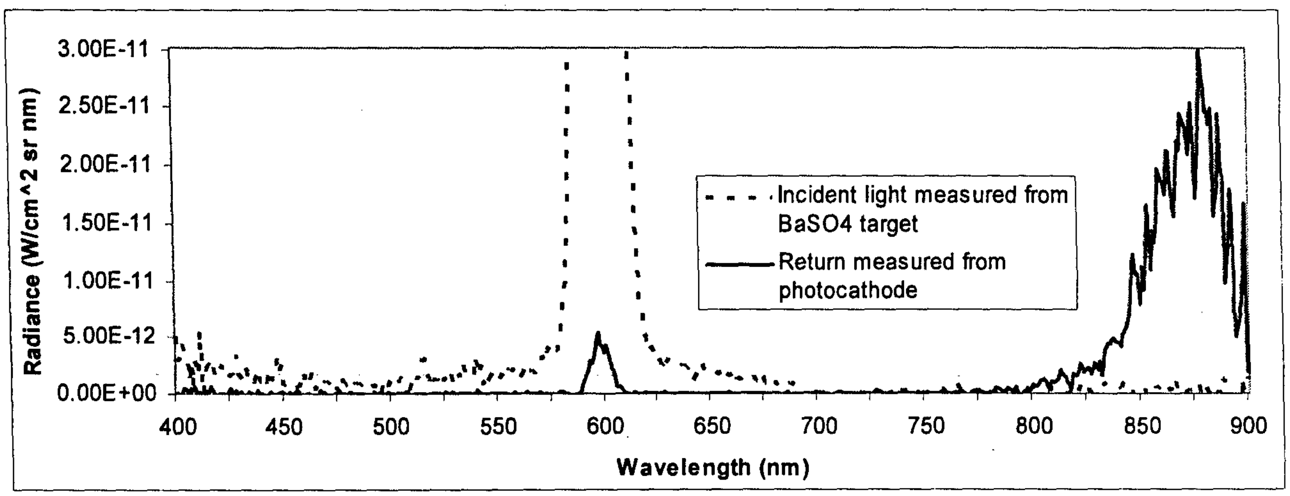

Figure 3. Example of stimulated IR emission.

The emission was present for all of the variables tested. The IR peak was evident in every angle tested including different incident angles of the visible light and different measurement angles. It occurred for different incident light intensities and wavelengths, and for all of the I^2 tubes tested. The amount of IR emission was proportional to the amount of incident light and varies from tube to tube. The magnitude of the IR emission peak radiance changed somewhat for some variables, but the location was always the same: between 800 and 900 nm.

Data obtained from the experiment were analyzed using spreadsheet and spectroradiometer software. The spectral curve was analyzed and integrals under the significant parts of each curve were calculated and compared. Integral information was calculated in terms of radiance and luminance (for the visible spectrum). The radiance of the incident light main peak (on the $BaSO_4$ reflectance standard) was compared to the radiance from 800 to 900 nm of the I^2T (see Figure 4 below for integral data). The range of 800-900 nm was chosen because the IR emission peak was in this area. Finally, a plot of the percentage of the 800-900 nm radiance was compared to the radiance of the $BaSO_4$ reflectance standard. Using this method, the percent of magnitude of the IR emission peak in the range of 800-900 nm was weighted by the amount of incident light (450 nm, 475 nm,..., 700 nm). These percentages will be used in the following, more detailed examination of the phenomenon.

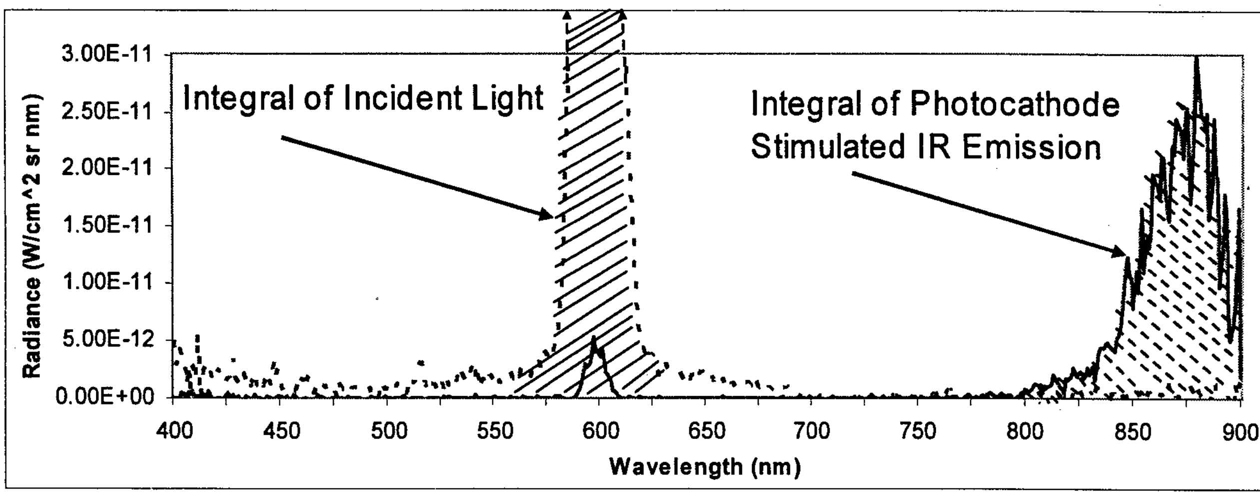

Figure 4. Example of area integrated for analysis.

The radiance values for a sample set of incident light data is given below in Figure 5. Here, the light is 30 degrees off axis from the $BaSO_4$ reflectance standard. Shown on this curve are the normal measurement light and a more intense light (bright) created by removing the light diffuser from the front of the light source. The bright light is about seven times the normal light. Here the maximum incident light occurs at 575 nm with the bright light source. This is the brightest condition used during this experiment. The luminance at this setting is equal to 4.922 fL, which is about a 1000 times the luminance of a full moon[2]. This shows that even using a light source that is so bright it would most likely damage the I^2T, the amount of IR radiance emitted by the photocathode is negligible.

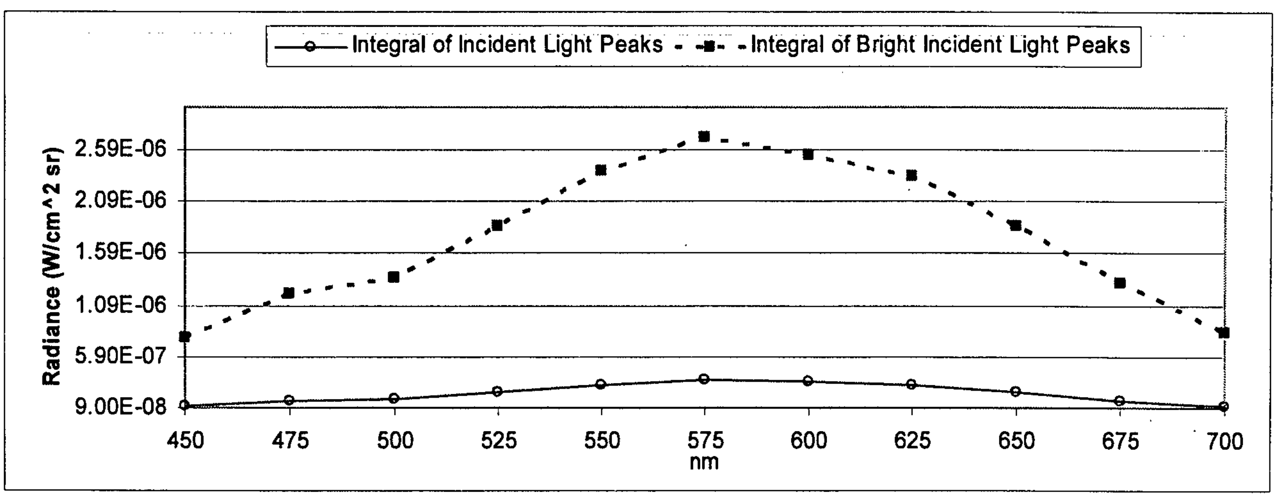

Figure 5. Incident light peak radiance.

Below, Figures 6-10 show the percent of IR radiance compared to the radiance of the incident light for different wavelengths. Each graph represents different variable conditions. From these figures, many conclusions are drawn. One can conclude that the percent of radiance is dependent on the type of I^2 tube used, the measurement angle, and the angle and wavelength of the incident light. It is not so much dependent on the radiance of the incident light. For all tubes, the IR emission is less prevalent in lower wavelengths of incident light. The biggest overall conclusion is that for every variable tested, the IR peak radiance does not exceed 0.41% of the incident light radiance. This is small compared to the incident light. It is doubtful that this is big enough to be the cause of the NVG visual performance loss described in the introduction.

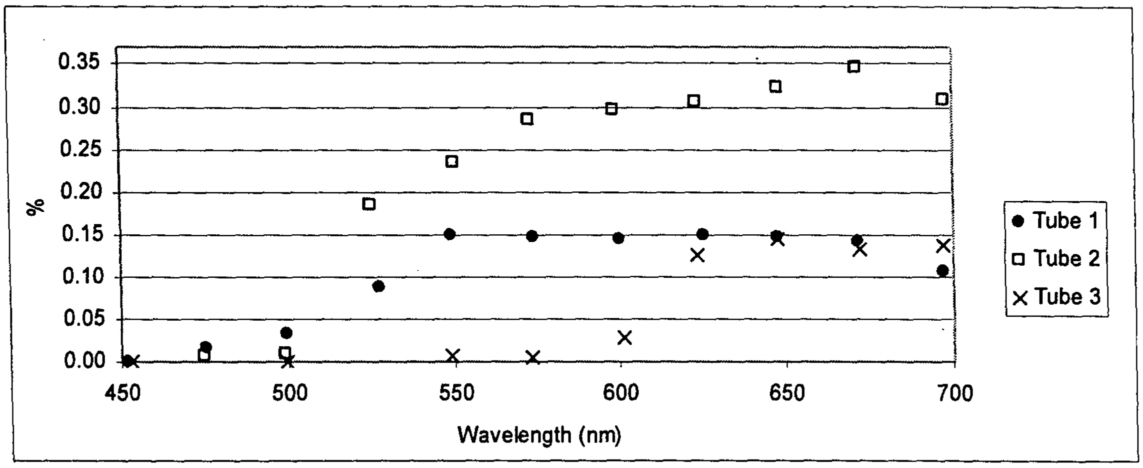

Figure 6. Comparing image intensifier tubes. Infrared emission expressed as a percentage of input illumination expressed as a function of illumination wavelength for three different image intensifier tubes.

As noted above, the magnitude of the IR emission varies from tube to tube. In

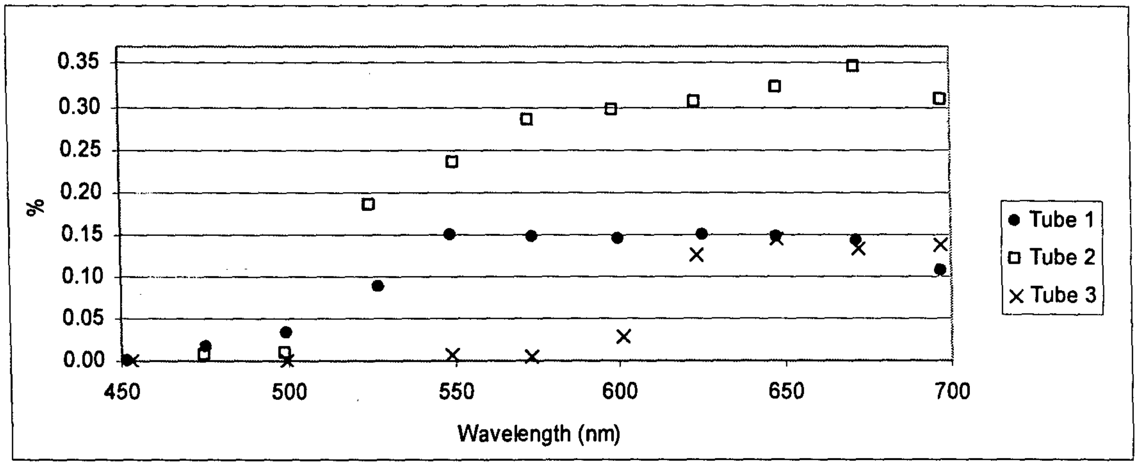

Figure 6, all variables are the same except for the I^2 tube. The authors would like to attribute this behavior to the age of the image intensifier tube. However, we were unable to determine tube age from our records. The mechanism causing the differences in IR emission between the three tubes is most likely a factor of tube structure or photocathode construction. However, these parameters were outside the scope of this experiment.

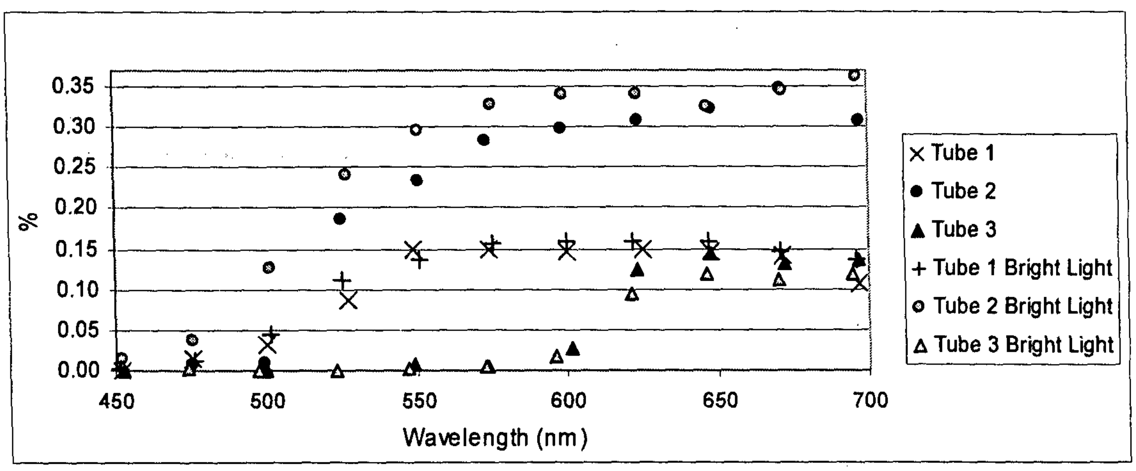

Figure 7. Comparing light levels. Infrared emission expressed as a percentage of input illumination expressed as a function of illumination wavelength for two different light intensities on three different image intensifier tubes.

The phenomenon was found to be fairly linear with increased photocathode irradiation. In

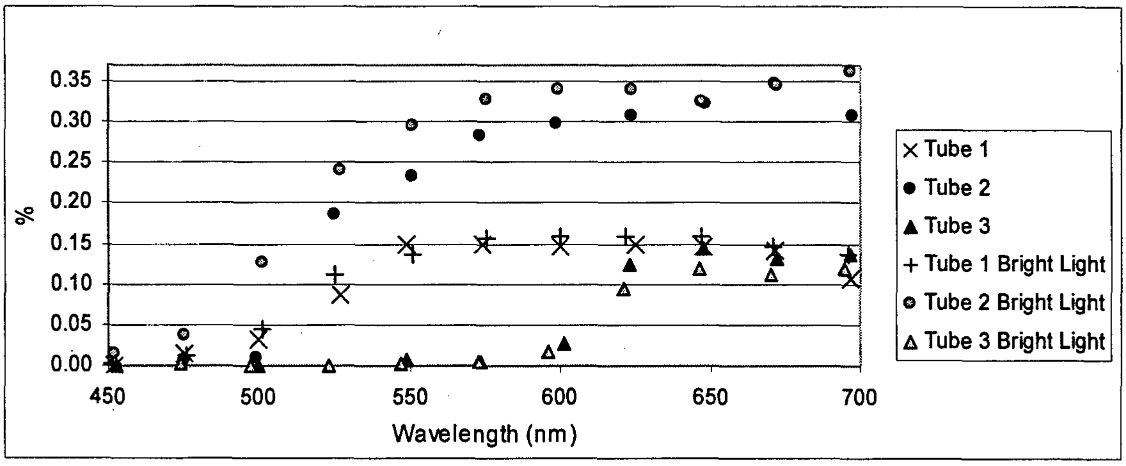

Figure 7, the strength of the phenomenon, as a percentage of the incident illumination, was plotted for all three tubes examined and for the two illumination levels examined. One should keep in mind that the radiance of the photocathode was seven times greater in the bright light condition than the normal condition. In this figure, relatively minor changes between the two illumination conditions can be seen. This suggests a slight nonlinearity with illumination. Perfect linearity would have yielded plots of the phenomenon, as a percentage of the photocathode illumination, which lay exactly on top of each other. Or, if the nonlinearity was due to the stimulation mechanism, all tubes of a given irradiation condition would lie in the same relative location relative to the other illumination condition in Figure 7. However, since the magnitude of the IR emission was so small to begin with, this nonlinearity may also be explained by measurement noise.

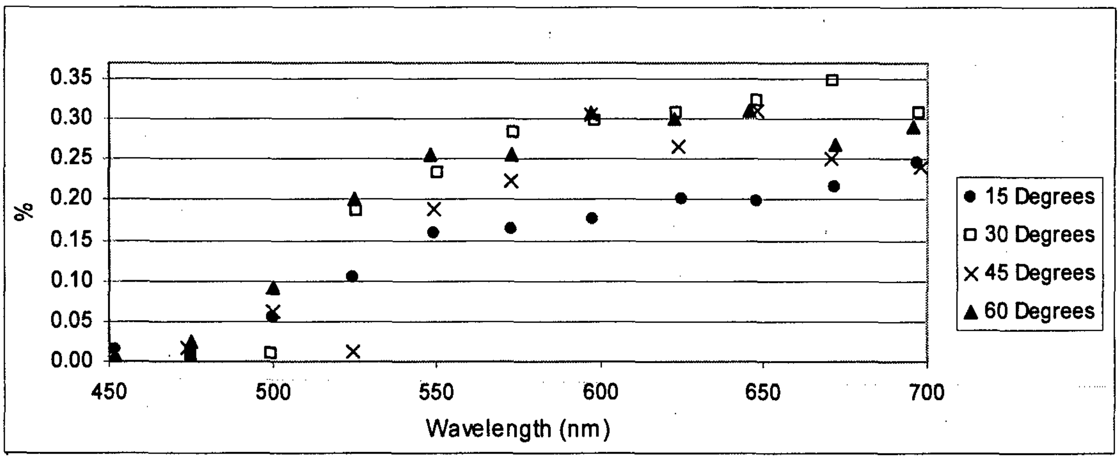

Figure 8. Comparing light angles. Infrared emission expressed as a percentage of input illumination expressed as a function of illumination wavelength for four different light illumination angles on image intensifier tube number 2 measured perpendicular to the photocathode surface.

In Figure 8, the phenomenon is plotted as a function of wavelength for four different illumination incidence angles. The data suggest that magnitude of the phenomenon increases as the photocathode is illuminated a greater and greater angle, indicating a non-Lambertian nature. The enhancement in magnitude may be as large as 50% when comparing the measurements at the 15-degree incidence angle to those at 60 degrees. However, one should note that the overall magnitude of the phenomenon is still small, regardless of incidence angle.

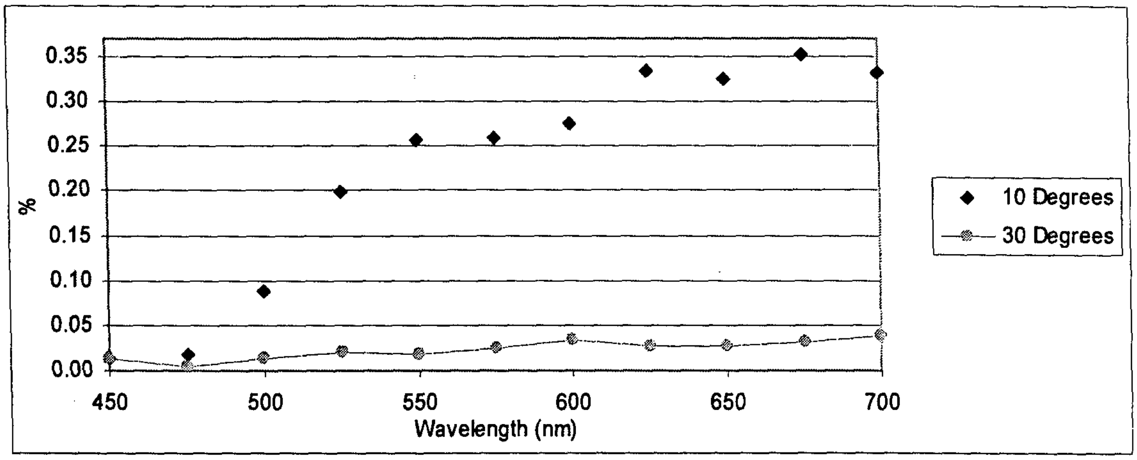

Figure 9. Measuring off-axis. Infrared emission expressed as a percentage of input illumination expressed as a function of illumination wavelength for measurements taken at 10 degrees and 30 degrees off axis of image intensifier tube number 2. Incident light is perpendicular to the I^2 tube face.

In

Figure 9, the incident light is perpendicular to the face of the I^2 tube and the measurement lens is detecting at different angles. In this case, the IR emission detected is much less for large measuring angles. This suggests that the phenomenon is not Lambertian in nature, exhibiting a stronger emission along the axis of illumination. This behavior should be studied more thoroughly in the future. For an optical imaging system, such as a night vision goggle, this suggests that the stimulated IR emission will propagate back through the objective lens primarily at relatively shallow angles to the optical axis, minimizing the chance that the IR radiation emitted from the photocathode would scatter off the sides of the lens cells, causing veiling glare.

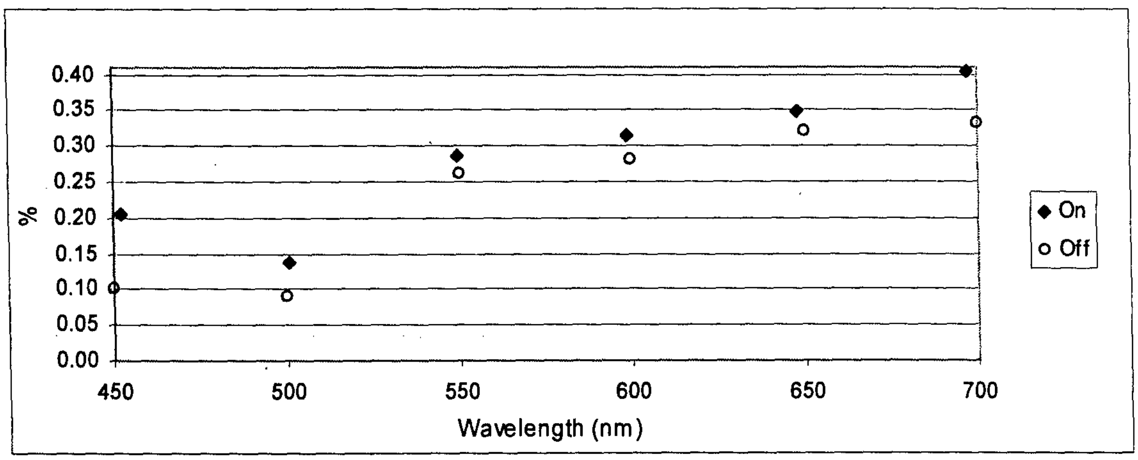

Figure 10. Tube on versus tube off. Infrared emission expressed as a percentage of input illumination expressed as a function of illumination wavelength for measurements taken with image intensifier tube number 2 on and off.

The impact of tube power on the IR emission was also examined. In Figure 10, the stimulated IR emission expressed as a percentage of the input irradiance is plotted as a function of irradiance wavelength for a single image intensifier tube, once without power ("Off") and once with power ("On"). These measurements showed little difference between the two tube states. This was somewhat of a surprise to the authors. The field created in the photocathode when power was applied to the tube was anticipated to significantly amplify the phenomenon. While measurements showed a slight increase, it was not the substantial enhancement anticipated. It is unclear to the authors what this behavior suggests.

4. DISCUSSION

One should keep in mind that the experiment described in this paper measured a stimulated IR emission from the image intensifier tube photocathode of, at most, only about 0.4% of the input illumination. The question of whether or not this stimulated emission could cause even noticeable visual performance losses, much the horrific visual impact claimed by some organizations within the Air Force Research Laboratory must be addressed. There are two possible scenarios by which this stimulated emission could cause problems. First, the light emitted from the photocathode could be reflected back to the photocathode and cause a veiling luminance. This veiling luminance then would reduce the perceived contrast of a target, in effect, reducing the overall system level modulation transfer function (MTF) of the device. In the second scenario, the stimulated IR induces a contrast loss due entirely to some mechanism internal to the photocathode. This discussion will concentrate on the former scenario. The latter scenario, while improbable is still possible, would require greater investigation and was considered outside the scope of this paper by the authors. Further investigation into the second scenario is reserved for future work.

In the first scenario described above, the visible light component of an image formed by the objective lens would stimulate an infrared emission. The stimulated IR light would have to leave the photocathode, be reflected back, off a surface in the NVG objective lens, and then come to rest on the photocathode, reducing the contrast of the original image. As measured, the radiance of the IR emission is only about 0.4 percent of the radiance of the incident light. The Fresnel reflection of the photocathode faceplate the IR emission would encounter as it leaves the image intensifier tube is included in this measurement. When the emission encounters the elements of the objective lens, a certain percentage is reflected. Since these surfaces are antireflection coated for the wavelengths included in the IR emission, these reflections are expected to be small. For this analysis, they are assumed to be about 2% per surface. This reflected light will then again pass through the air/glass interface of the image tube faceplate, assumed to be approximately 95% since it is not antireflection coated. Combining these Fresnel contributions with the strength of the stimulated IR emission, one can see that the stimulated IR emission will contribute slightly less than 0.008% of the stimulating radiance to the photocathode per optical surface in the NVG objective lens.

The magnitude of the phenomenon required to cause significant contrast loss was examined using the modulation contrast equation[3], Equation 1, where *B* represents the radiance of the bright side of a contrast edge and *D* represents the radiance of the dark side. Assuming that the veiling light returning to the photocathode is uniform, represented by V_{IR}, the light would simply add to both sides of the contrast edge. The viel can be incorporated in Equation 1 by adding it to both the bright and dark radiances. The modified Equation 1 can be simplified to yield Equation 2. Plotting as a function of the ratio of the veiling radiance that has returned to the photocathode to the radiance of the bright side of the target yields Figure 11. From this figure, one can see that in order to reduce the observed contrast by about half, the veiling radiance must be 50% to 60% of the radiance of the bright side of the target. If this data is weighted by the Fresnel components needed to describe the return of the stimulated IR to the photocathode, one can see that the radiance of the stimulated emission would have to be many times the radiance of the incident image to induce the kind of reduction in observed contrast attributed to the phenomenon.

$$C = \frac{B-D}{B+D} \qquad (1)$$

$$C_O = \frac{B-D}{B+D+2V_{IR}} \qquad (2)$$

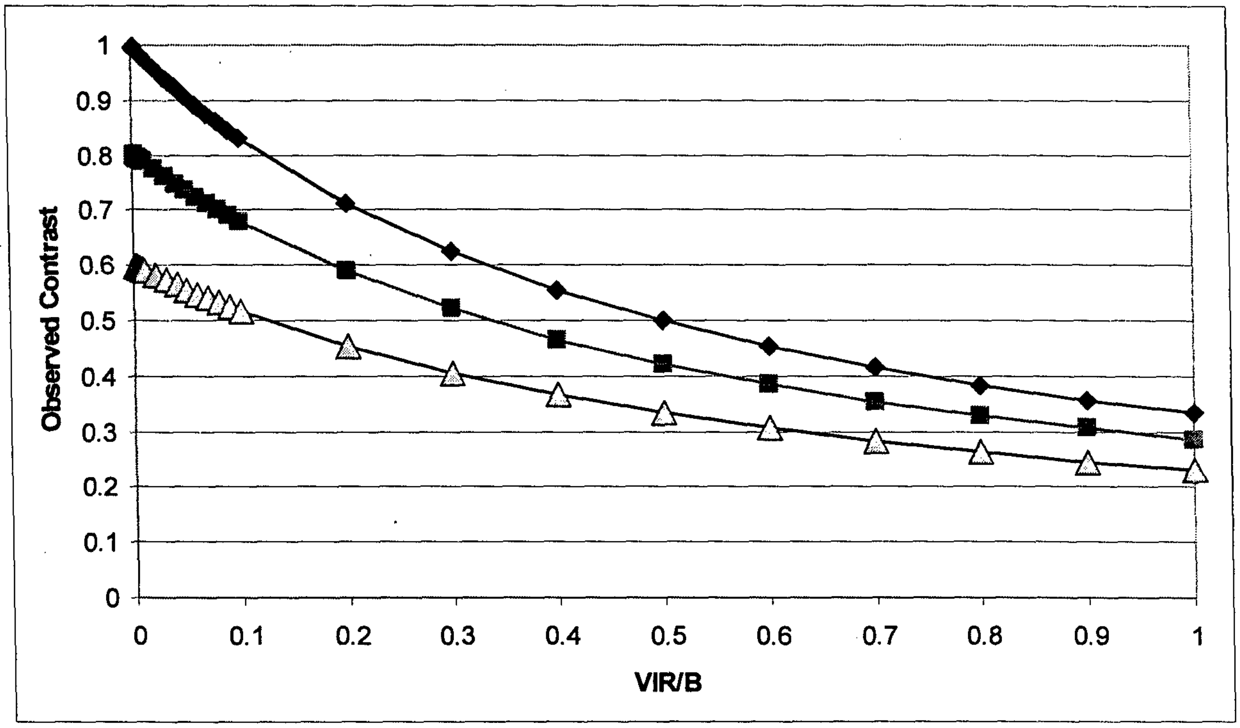

Figure 11. Observed contrast for three different contrast edges (100%, 80%, and 60%) plotted as a function of the ratio of the stimulated veiling and bright edge radiances.

5. CONCLUSION

In conclusion, a bizarre IR emission is present and can be measured from the photocathode of an I^2 tube hit by incident light. When incident light that is almost 1000 times the full moon equivalent is used, an IR radiance of only 8.9E-9 W/cm^2sr is emitted which is 0.41 % of the incident light. Due to the small magnitude of the phenomenon, it is not considered significant enough to be the source of the visual performance loss reportedly seen in night-vision goggles.

Not surprisingly, our work shows that the phenomenon is wavelength dependent. It is relatively linear with the photocathode radiance due to input illumination. The lack of linearity is believed to be due more to measurement error than nonlinearity of the phenomenon. The application of power to the tube did not greatly change the magnitude of the stimulated emission. The emission was surprisingly directional, emitting primarily normal to the photocathode, and not Labertian in nature as anticipated. This behavior reduces the probability that the stimulated emission is interfering with visual performance. In addition, the strength of the phenomenon was somewhat related to the illumination angle. The reason for this behavior could not be determined from this effort and should probably be studied in greater detail in future work.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the help from David Sivert of Sytronics, Inc and Terry Trissell of Northrop Grumman IT/IS. Their contribution to equipment set-up and calibration is much appreciated.

REFERENCES

1. Saleh, B.E.A., Teich, M.C., *Fundamentals of Photonics*, John Wiley and Sons, New York, 1991.

2. Bartell, Richard J., M.S. and Mitchell, Charles F. (1993). *Operator's Manual, Night Vision Goggle Evaluation Measurement Equipment Version 1.1.* Logicon Technical Services, INC. Dayton, OH. Pg. 10.

3. Kottler, F., Perrin, F.H., "Imagery of one-dimensional patterns," *Journal of the Optical Society of America*, Vol. 56, 1966, pp. 377-388.